Statue of Liberty: A Risk Analysis

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National Park Service

Agenda

- Overview of Project Scope
- Evaluation Steps
  - Task 1 – Code Analysis
  - Task 2 – Fire Modeling
  - Task 3 – Egress Modeling
  - Task 4 – Mitigation Strategies
  - Task 5 – Risk Analysis
  - Task 6 – Alternatives Assessment
- Summary
- Progress of Construction
- Questions

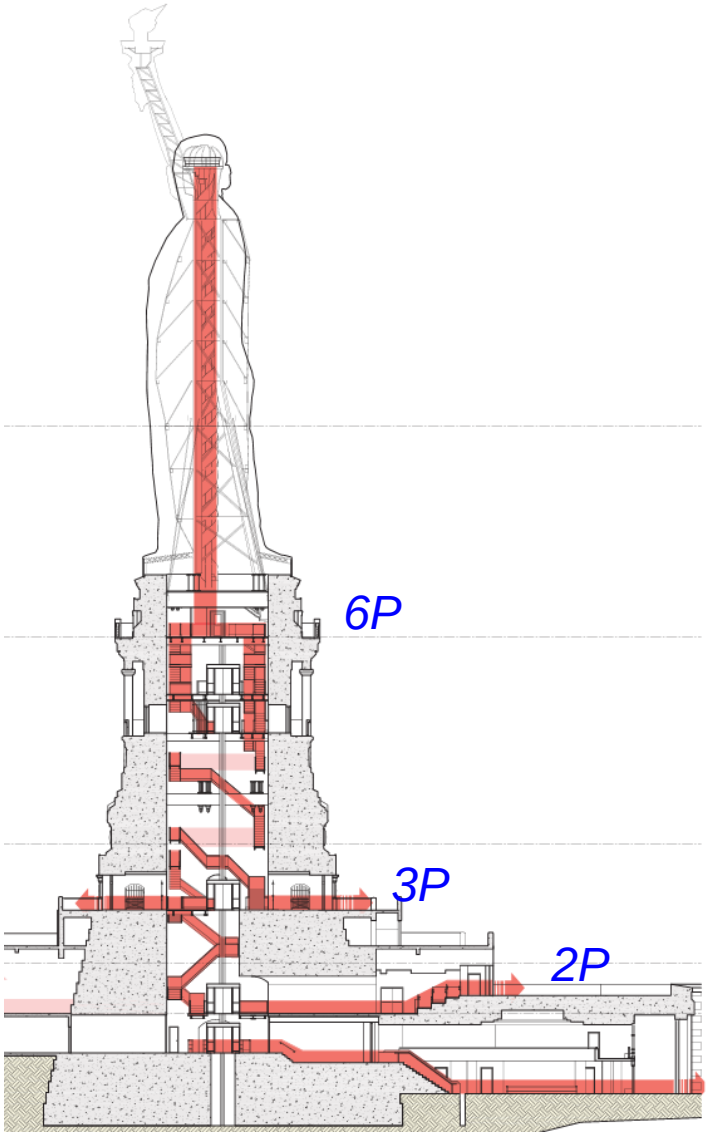
Project Scope

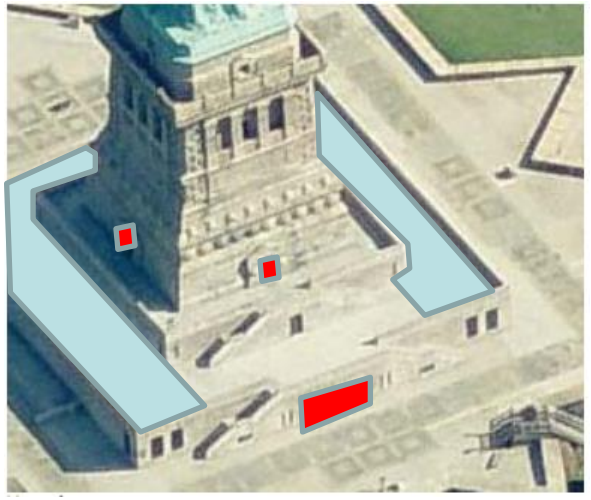
- The National Park Service (NPS) contracted a performance-based life-safety and emergency management assessment of the Statue of Liberty
- Principal Researchers; Mike Ferreira and Eric Rosenbaum
- Key questions:
  - Can you satisfy code requirements with respect to the Crown?
  - Physical changes required to bring the facility closer into code compliance?
  - How can the NPS minimize the life and safety risks?
  - How many people could be safely accommodated?
  - What operational procedures would need to be in place?

Selection Process

- Meetings including all major stakeholders:
  - NPS national and regional representatives
    - Management and fire protection personnel.
  - Statue of Liberty superintendent and staff
  - Historic / conservation experts
  - Construction management and cost estimator
  - Marketing and visitor experience staff
- Evaluated issues:
  - Historic impacts
  - Impact on visitors
  - Cost (construction / staffing)

Statue of Liberty National Monument

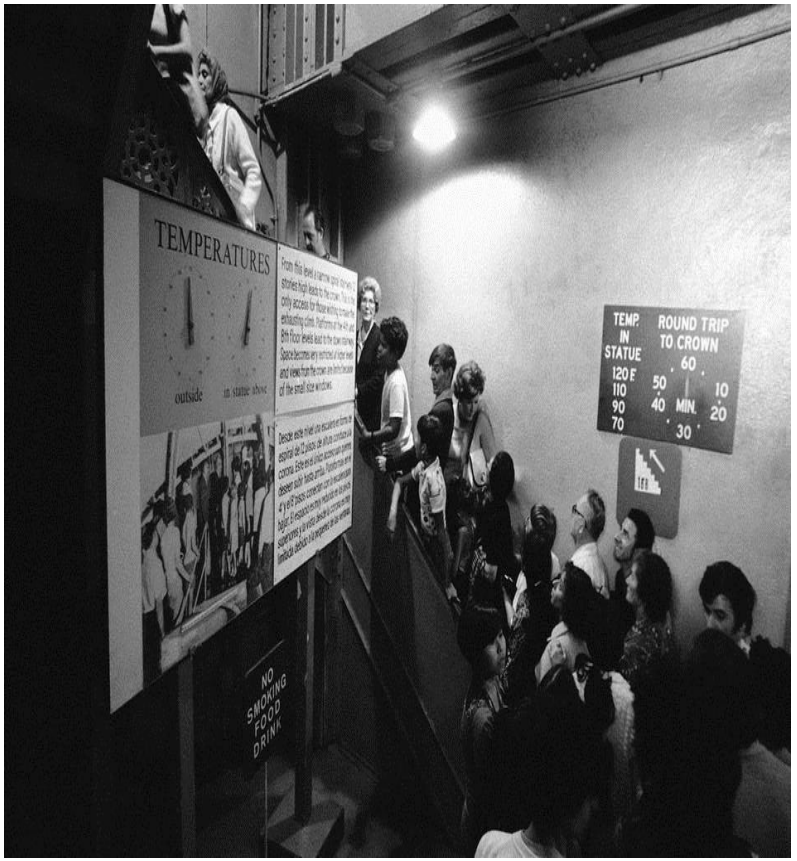




Museum

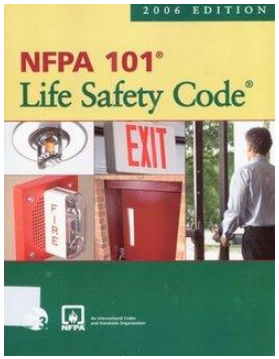
Exits

History

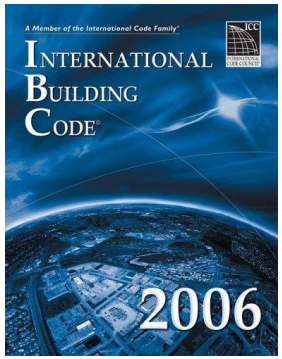

TEMPERATURES
outside
TEMP. IN STATUE
120 F
110
90
70
ROUND TRIP TO CROWN
60
50
40
MIN.
30
10
20
NO SMOKING FOOD DRINK

Task 1 – Code Analysis

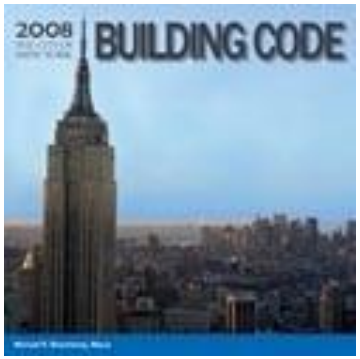
- NFPA 101, *Life Safety Code (2006)*
- ICC, *International Building Code (2006)*
- *2008 New York City Building Code*



New & Existing Construction



New Construction



New Construction

Code Analysis & Findings

- Construction features
  - *Construction type*
  - *Protection of vertical openings*
- High-rise building criteria
- Fire protection systems
  - *Sprinkler & standpipe*
  - *Fire alarm*
  - *Smoke purge*
- Means of Egress
  - *Occupant load*
  - *Number & capacity*
  - *Arrangement*
  - *Exit discharge*
  - *Stairs, doors, ramps*
  - *Emergency lighting & exit signage*

Code Analysis & Findings

Construction Features

- Statue construction is not compliant.
  - Copper on unprotected iron skeleton
  - Fire resistive construction required
- Vertical openings are not compliant.
  - Main lobby area
  - West lobby stair (open at 2P)
  - Pedestal core (1P-6P)
  - Statue (7P-Crown)

Code Analysis & Findings

Pedestal Core

- 6-story vertical opening containing all egress stairs from upper levels.
- Potentially meets intent of codes for shaft requirements.
  - Does not comply with requirements for exit enclosures.

Code Analysis & Findings

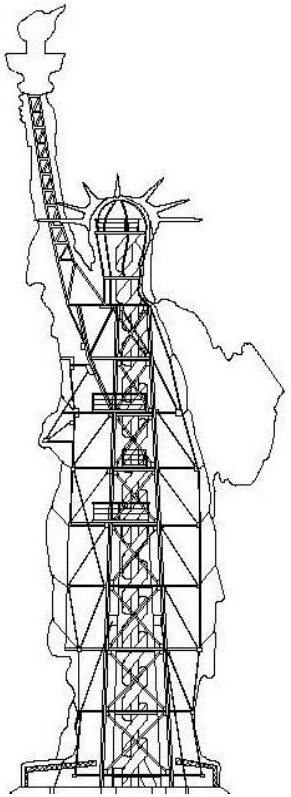
Statue (7P – Crown)

- Codes do not specifically address.
- Potentially classified as mezzanine.
  - Common path of travel >75 ft.
  - Enclosed stair or 2 means of egress.

Code Analysis & Findings

High-Rise Building Criteria

- Buildings with occupied floors > 75 above lowest level of fire department vehicle access.
  - Complete sprinkler protection
  - Smoke detection in select spaces
  - Emergency voice/alarm communication system
  - Fire department communication system
  - Fire command center
  - Enclosed elevator lobbies
  - Emergency power systems
  - Smokeproof exit enclosures
  - Seismic considerations
  - Impact resistant stair enclosures
  - Exit path markings
  - Limitations of use of open web steel joists



Code Analysis & Findings

Fire Protection Systems

- Automatic sprinkler system – required throughout
  - Sprinkler protection provided in both Pedestal & Statue
  - Statue may not be considered fully-sprinklered
  - Likely meets intent of code
- Standpipe system - required
  - Standpipe system provided
- Fire alarm system – required
  - Manual & automatic fire alarm system provided
  - Automatic smoke detection provided (spot-type, Analaser)
  - Voice/alarm communication system not provided
- Smoke purge system – required per NYCBC
  - Not provided

Code Analysis & Findings

Occupant Load Summary

Level	Calculated Occupant Load
Level 0P	529
Level 1P	657
Level 2P	276
Level 3P	88
Level 4P	59
Level 5P	26
Level 6P	183
Level 7P	9
Crown platform	5
Total	*1,832*

Code Analysis Findings

<u>Egress Components – stairs, doors, ramps</u>

- Most stairs-noncompliant
- Several egress doors-noncompliant
- Ramp at sally port exit-noncompliant
- Unique issues-stair / door to Level 7P and double-helix stair to Crown
  - Two intertwined spirals; one leads down the other goes upwards

Code Analysis Conclusions

- Structure does not comply with criteria.
- Replacing double-helix stair does not fully address code issues for Crown.
- Levels 4P-6P are effectively served by only a single exit.
- The exterior walkways at Levels 3P and 2P-exit discharge onto top of Fort Wood. Temporary wood stairs provide access to grade.

Task 2: Fire Modeling

- General Approach
  - *Model the structure*
  - *Develop design fire scenarios*
  - *Evaluate fire environment as a function of critical tenability criteria*
    - *Temperature*
    - *Toxicity (CO Concentration)*
    - *Visibility*

Construction of the Model

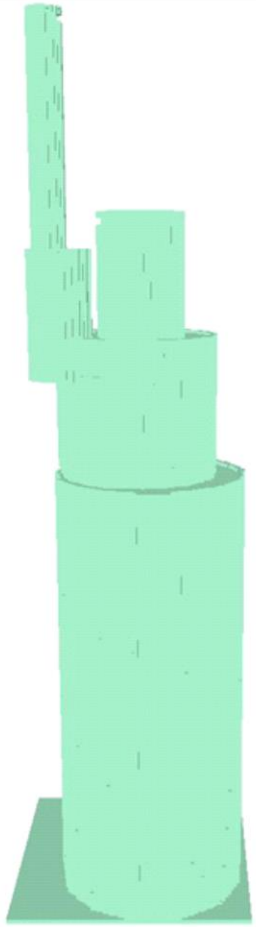
- Fire Dynamics Simulator (FDS) Model
  - Model developed by the National Institute of Standards and Technology (NIST)
  - Model intended to handle isolated and spreading fires in human habitable spaces.
  - Version 5 utilized
  - Special V&V not required by the Park Service; existing V&V sufficient

Model Fidelity

- Decisions had to be made as to what level of effort to put into model fidelity.

3D CAD Model

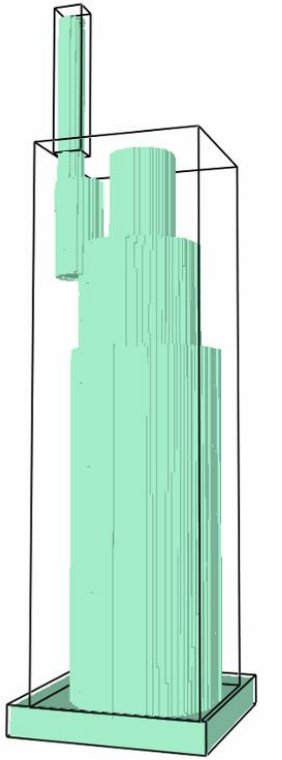
FDS Conversion



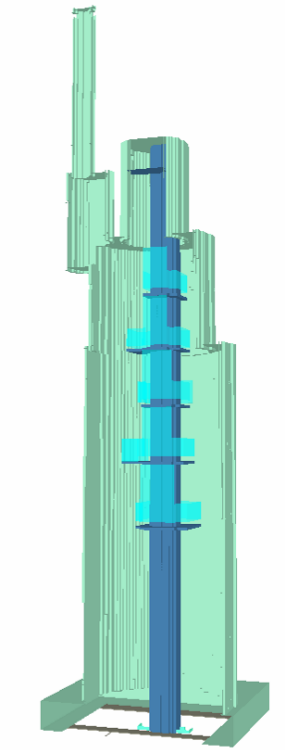
Volume Approximation

Statue Model Domain

- A simplified representation of the complex Statue geometry was constructed.



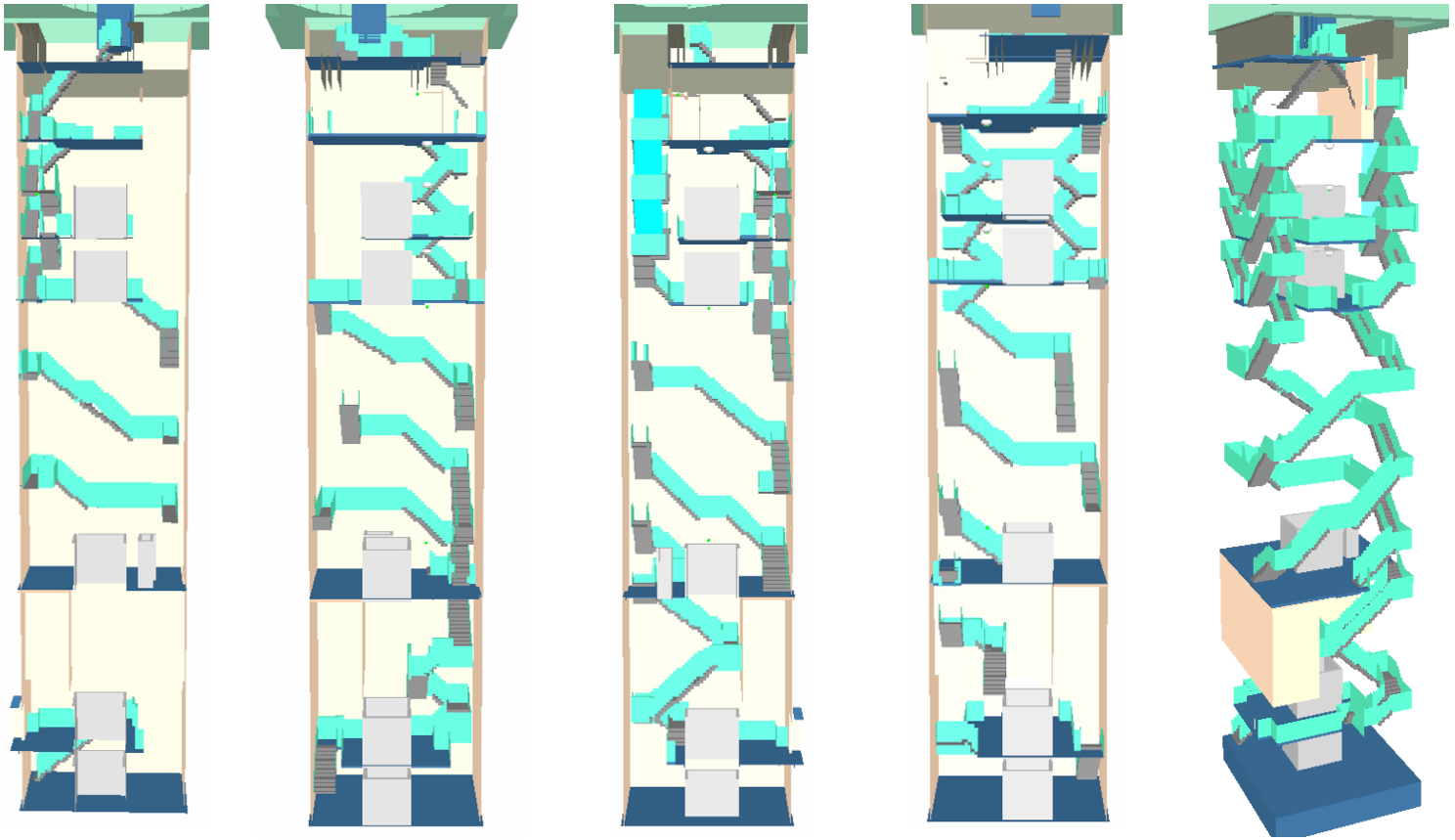
Exterior



Interior

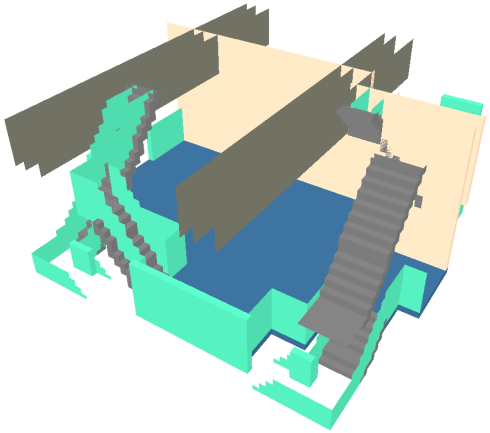
Pedestal Model Domain

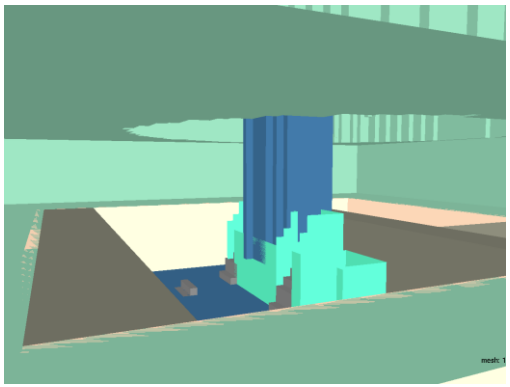
- A detailed representation of the interior Pedestal geometry was constructed.

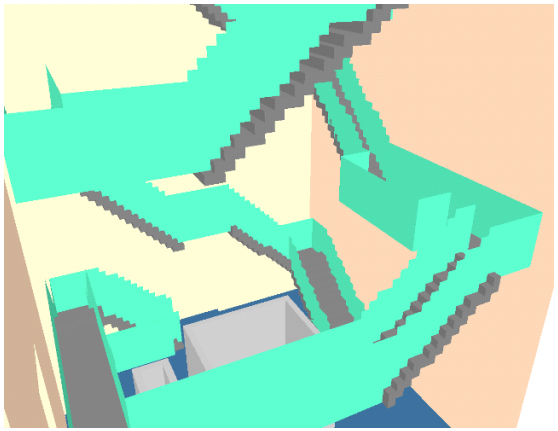


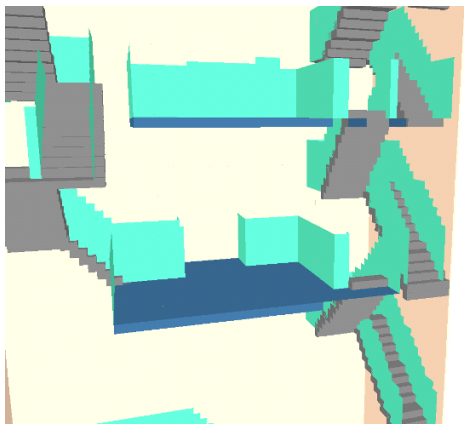
Pedestal Details

- The Pedestal geometry included all stairs, handrails, and interior obstructions.



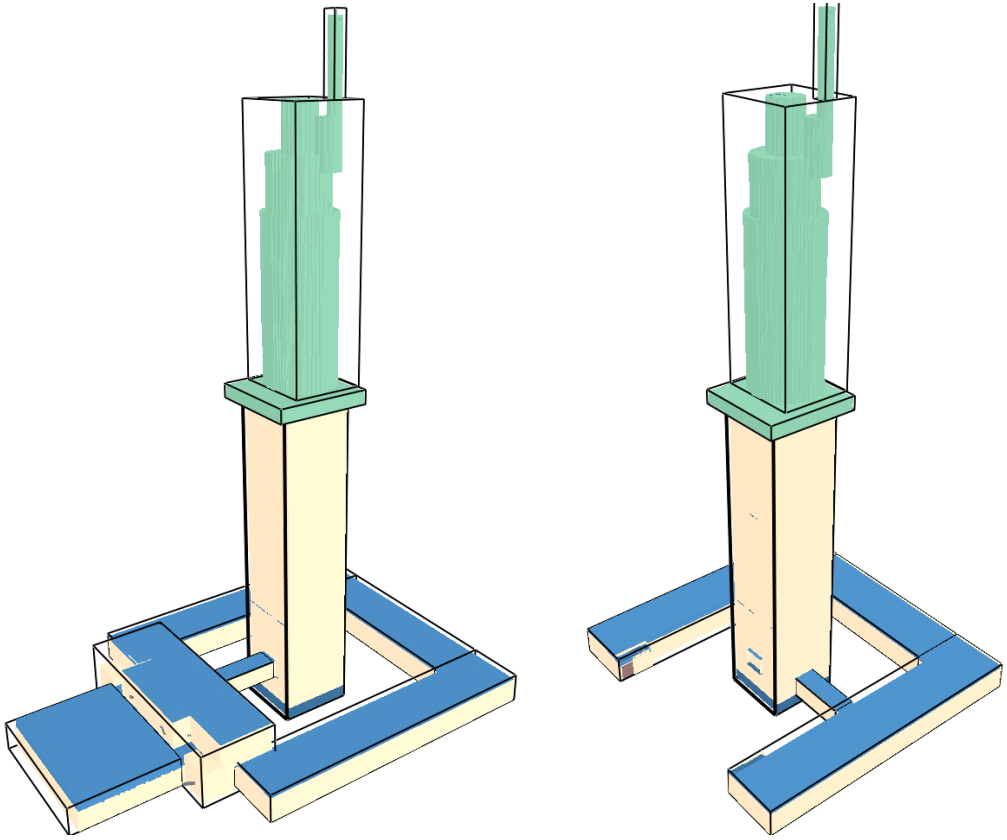






Museum Fire Domains

- Additional spaces on 1P and 2P were added for museum fire simulations.



Indirect Spread ***Direct Spread***

Develop Design Fire Scenarios

- Based on NFPA 101, *Life Safety Code*, performance-based scenarios:

Fire	Location	Peak Heat Release Rate	Growth rate	Post Peak Behavior	Fuel Properties
Trash Fire	**2P**	**500**	**Fast**	**Decay**	**Plastics/ Cellulosic**

Summary of Design Fires

- Trash Fire
- Storage Fires
  - Sprinkler Controlled
  - Sprinkler Suppressed
- Museum Displays
  - Sprinkler Controlled
  - Unsprinklered
- Elevator Hydraulic Fluid Spill
- Gasoline Spill (Intentional)

Critical Tenability Criteria

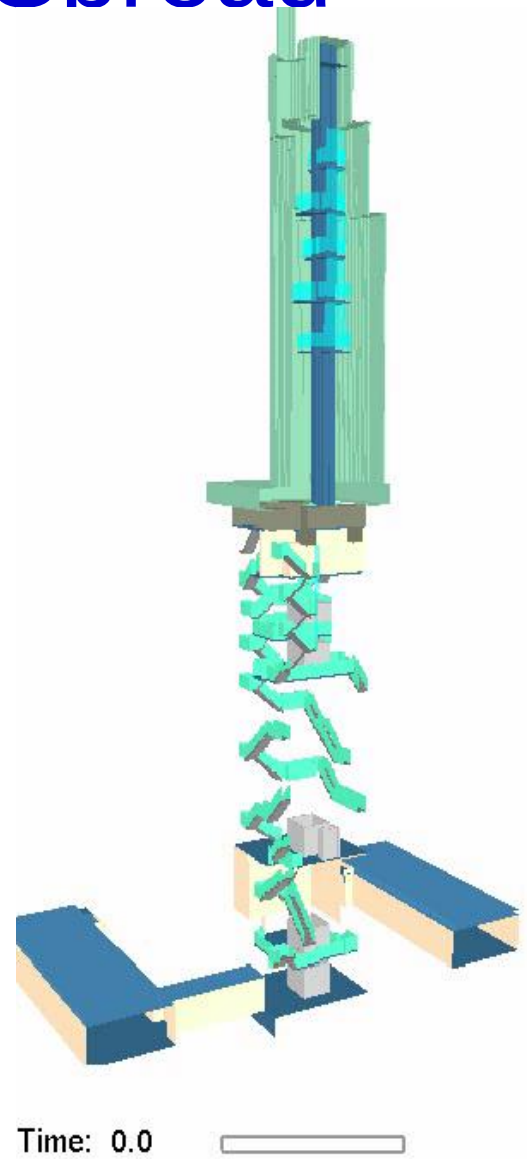
Criteria	Limit
Temperature	< 76°C (168°F)
CO Concentration	< 1.2 × 10-3 mol/mol (1200 ppm)
Visibility	> 10 m (30 ft)

Critical Visibility Times (ASET)

- For each fire scenario, the time to reach the critical visibility threshold was calculated for:
  - Level 3P – Highest level occupants could access the exterior of the structure, at the top of Fort Wood
  - Level 6P – Exterior observation level at top of Pedestal
  - Level 7P – Base of statue
  - Crown – Observation platform

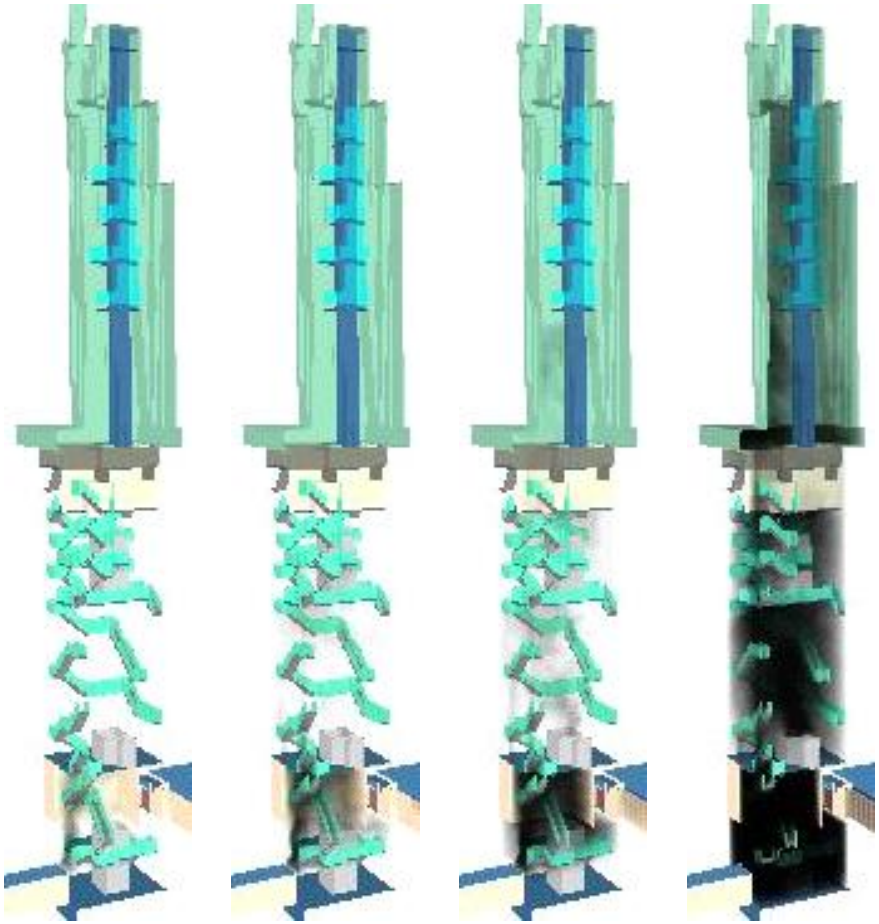
Extent of Smoke Spread

- Sprinkler controlled museum display fire (1P)



Extent of Smoke Spread

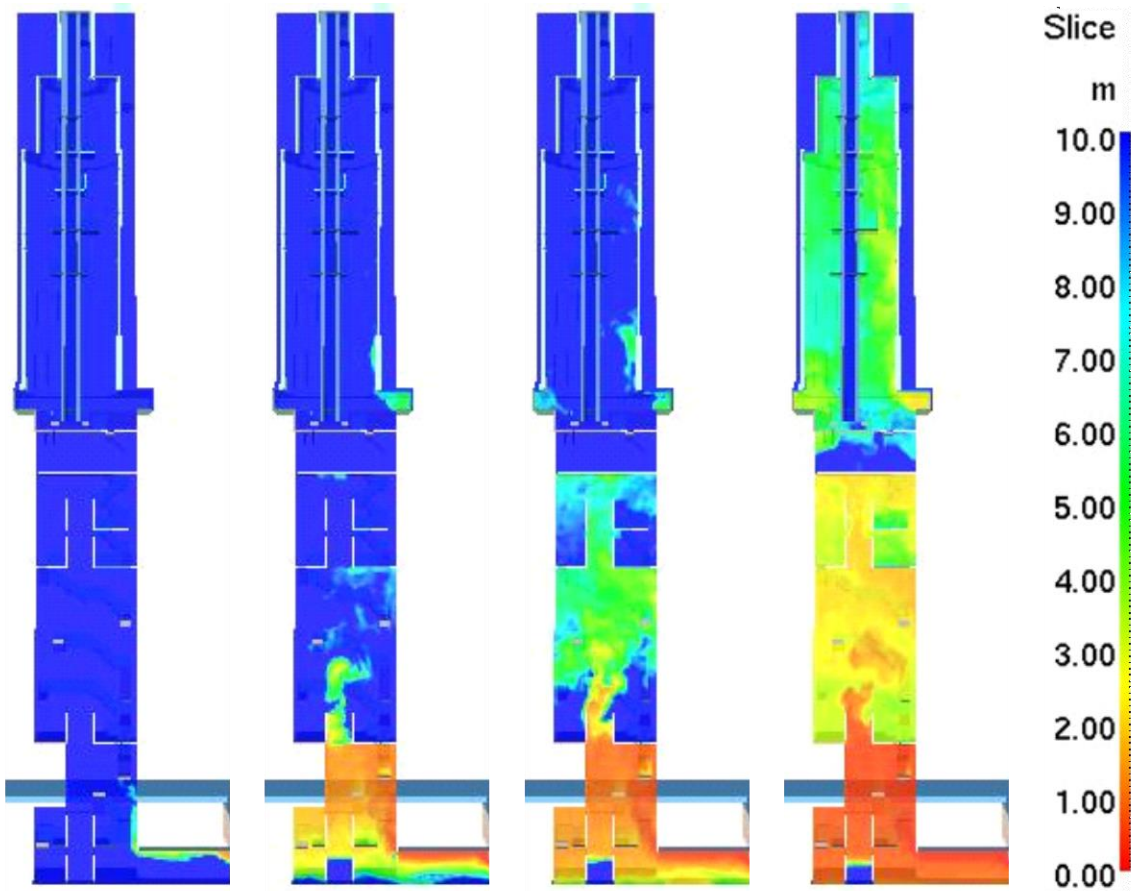
- Sprinkler controlled museum display fire



150 sec 212 sec 280 sec 630 sec

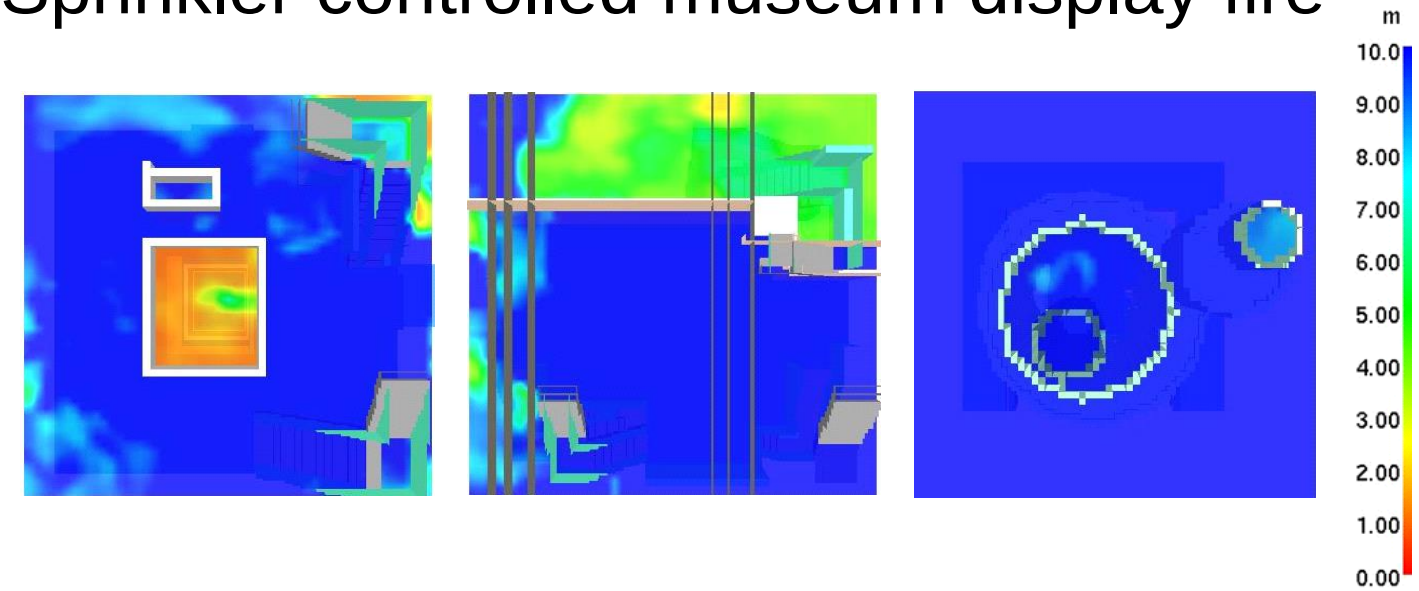
Visibility

- Sprinkler controlled museum display fire



Visibility

- Sprinkler controlled museum display fire



3P - 690 sec 6P - 810 sec Crown - 910 sec

Detection [sec (min)]	Approx. Time to Reduced Visibility [sec (min)]		
	3P	6P	Crown
22 (0.4)	690 (11.5)	810 (13.5)	910 (15.2)

Task 2 Summary

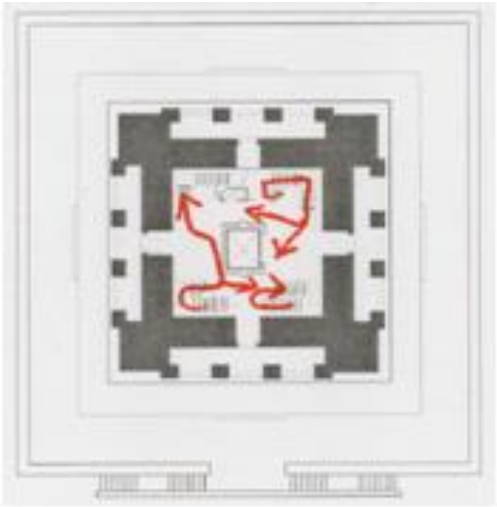
- Fires could impede egress due to exit via single enclosure.
- Fires where the passive fire barriers close / remain intact are not likely to seriously impede egress.
- Large instantaneous fires within the core are a significant threat to safe egress.

Task 3: People Movement

- General Approach
  - *Establish emergency egress performance*
  - *Derive procedural/structural recommendations*
  - *Receive feedback*
  - *Determine consequences of recommendations on non-emergency egress and access.*
  - *Modify recommendations/non-emergency operations if necessary*

Task 3: People Movement

- Sources of information



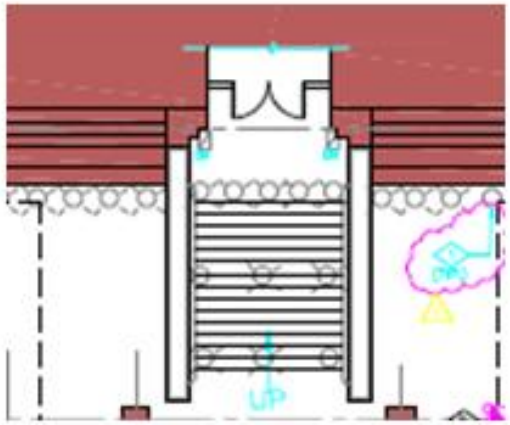
Egress Route Diagrams

Direct Observation

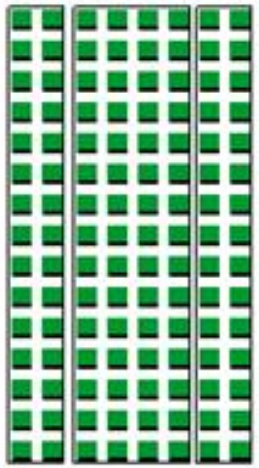
Task 3: Model Construction

- Model of the Monument constructed using buildingEXODUS
  - *Developed by the University of Greenwich (UK)*

(a)On site photograph

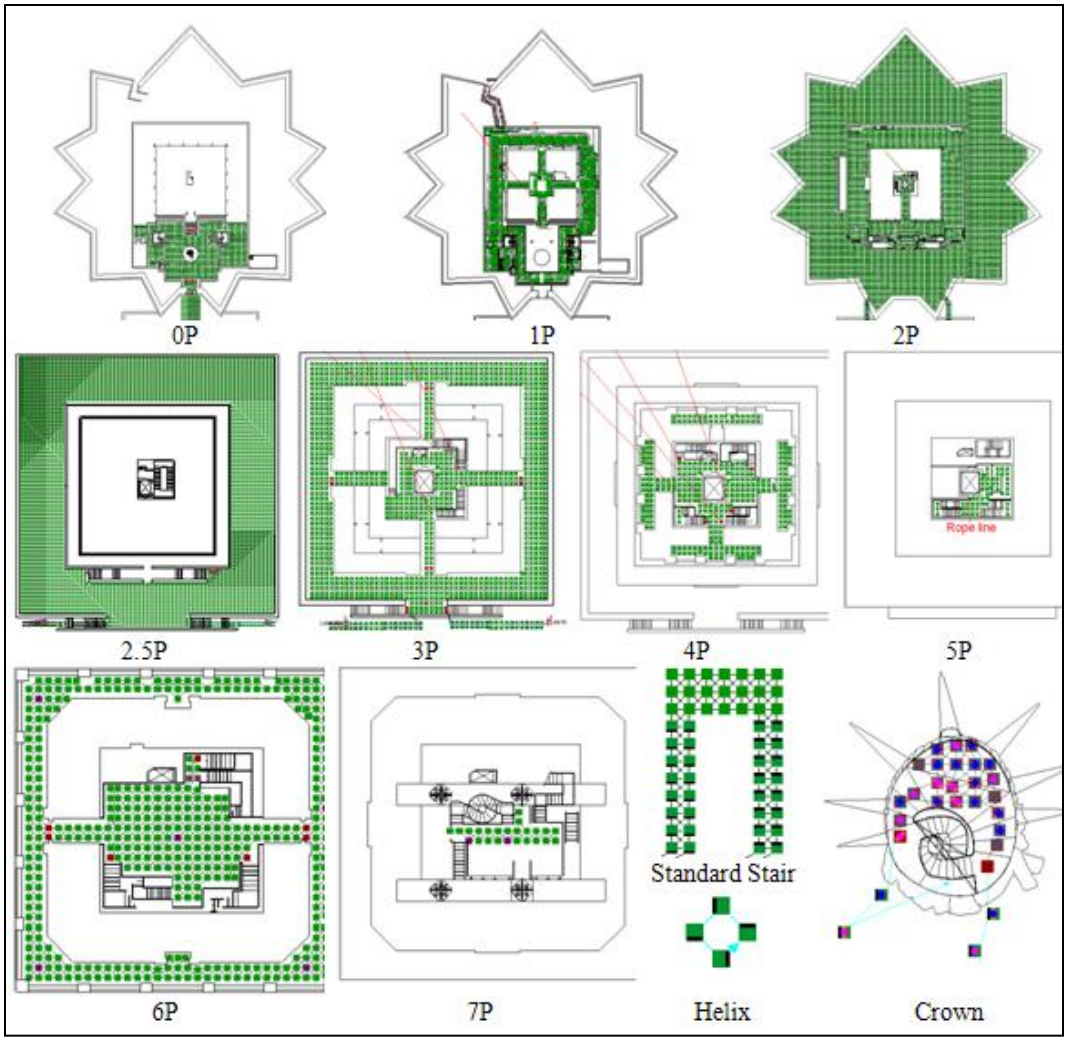


(b)Architectural diagram



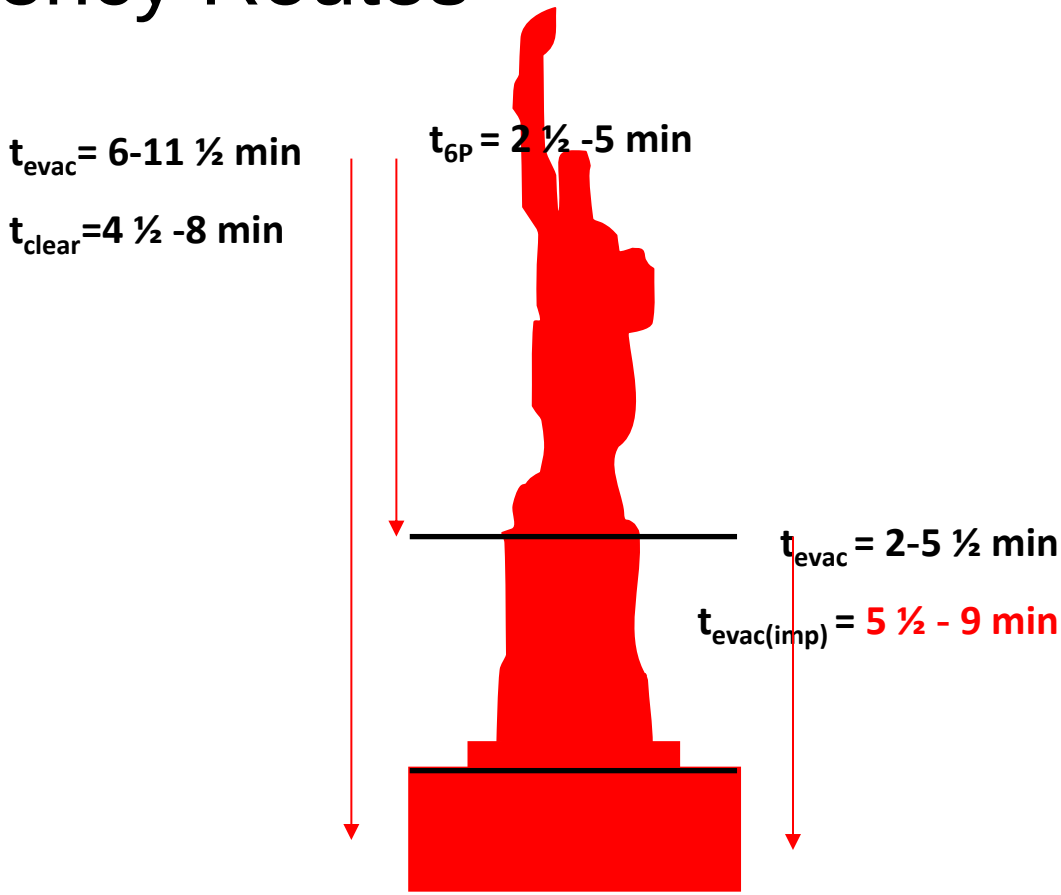
(c)Representation in EXODUS. Note separation into three adjacent stairs.

Task 3: EXODUS Model



Task 3: Evaluation - Individual

- Emergency Routes



- *Results consistent with observation*

Task 3: Raw Egress Times

- Results Overview
  - Individual from Crown - 4 ½ -8 min
  - Pedestal (Basic) – 4 ½ min
  - Monument (Basic) – 8 min
  - Pedestal (Reasonable) – 11 min
  - Monument (Reasonable) – 15 min
  - Monument (Code) – 25 min
  - Monument (Managed) – 12 min
  - Crown – 10 -12 min

Task 3: Egress Result Matrix (RSET)

- A matrix of RSET values was constructed considering a range of variables:
  - Response Time
    - 0-30 sec (staff guided)
    - 30-60 sec (voice notification)
    - 30-360 sec (existing – museum occupancies)
  - Egress Condition
    - Pedestal/Statue
    - Pedestal/Statue (loss of stair)
    - Statue only (off hours)
  - Statue / Pedestal Occupant Load
    - Statue tour group size.

Comparison of ASET vs. RSET

- ASET vs. RSET can be compared for the 13 fire scenarios as a function of:
  - Evacuation scenario.
  - Occupant reaction time.
- The ASET vs. RSET comparison table was color coded as follows:
  - Red = ASET< RSET – 30 sec
  - Yellow = ASET +/- 30 sec
  - Green = ASET > RSET + 30 sec

Example 1: Scenario Fails

Fire Scenario A			Required Safe Egress Time (RSET)								
Available Safe Egress Time (ASET) *Crown (360 sec), 6P (250 sec), 3P (170 sec)*			0-30 sec. reaction			30-180 sec. reaction			30-360 sec. reaction		
Description	*Pop. Size*	*Statue Pop.*	Crown	6P	3P	Crown	6P	3P	Crown	6P	3P
Pedestal Only	450	NA	NA	217	734	NA	350	771	NA	500	776
Pedestal/Statue	450	60	225	456	771	373	610		529	773	1033
	450	30	183	401	790	329	542	857	504	712	942
	450	15	187	391	804	320	536	812	487	655	875
Pedestal/Statue (Loss of Stair)	450	60	413	665	927	NA	NA	NA	768	1018	1266
	450	30	402	643	904	NA	NA	NA	504	712	942
	450	15	256	496	797	NA	NA	NA	487	655	868
Statue Only (off-hours)	60	60	230	460	711	373	610	860	531	769	1042
	30	30	182	409	639	329	542	776	501	714	958
	15	15	174	405	630	320	536	774	491	652	944

Example 2: Scenario Passes

Fire Scenario B			Required Safe Egress Time (RSET)								
Available Safe Egress Time (ASET) *Crown, 6P, 3P (1200+ sec)*			0-30 sec. reaction			30-180 sec. reaction			30-360 sec. reaction		
Description	*Pop. Size*	*Statue Pop.*	Crown	6P	3P	Crown	6P	3P	Crown	6P	3P
Pedestal Only	450	NA	NA	109	626	NA	242	663	NA	392	668
Pedestal/Statue	450	60	117	348	663	265	502	769	421	665	925
	450	30	75	293	682	221	434	749	396	604	834
	450	15	79	283	696	212	428	704	379	547	767
Pedestal/Statue (Loss of Stair)	450	60	305	557	819	NA	NA	NA	660	910	1158
	450	30	294	535	796	NA	NA	NA	396	604	834
	450	15	148	388	689	NA	NA	NA	379	547	760
Statue Only (off-hours)	60	60	122	352	603	265	502	752	423	661	934
	30	30	74	301	531	221	434	668	393	606	850
	15	15	66	297	522	212	428	666	383	544	836

Example 3: Scenario is Borderline

Fire Scenario C			Required Safe Egress Time (RSET)								
Available Safe Egress Time (ASET) *Crown (910 sec), 6P (810 sec), 3P (690 sec)*			0-30 sec. reaction			30-180 sec. reaction			30-360 sec. reaction		
Description	*Pop. Size*	*Statue Pop.*	Crown	6P	3P	Crown	6P	3P	Crown	6P	3P
Pedestal Only	450	NA	NA	109	626	NA	242	663	NA	392	668
Pedestal/Statue	450	60	117	348	663	265	502	769	421	665	925
	450	30	75	293	682	221	434	749	396	604	834
	450	15	79	283	696	212	428	704	379	547	767
Pedestal/Statue (Loss of Stair)	450	60	305	557	819	NA	NA	NA	660	910	1158
	450	30	294	535	796	NA	NA	NA	396	604	834
	450	15	148	388	689	NA	NA	NA	379	547	760
Statue Only (off-hours)	60	60	122	352	603	265	502	752	423	661	934
	30	30	74	301	531	221	434	668	393	606	850
	15	15	66	297	522	212	428	666	383	544	836

Summary of Existing Conditions

- ASET vs. RSET (13 fire scenarios)
  - Subset of fire scenarios pass,
  - Subset fails and
  - Subset demonstrate borderline results.
- The next step -develop and evaluate hazard mitigation strategies (candidate fire safety designs).

Task 4: Mitigation Strategies

- Candidate fire safety designs were considered.
- Six design packages were developed
  - Increasing in cost/complexity and level of code compliance.
  - No designs were considered that were visible from the exterior of the structure.
- Cost estimates were developed for individual design features and design packages
- Meetings were conducted with stakeholders to assess/approve options

Design Package A

- *Minor Structural Improvement + Administrative Controls Only*

Structural Improvements	Fire Protection System Improvements	NPS Administrative Needs
1. Install magnetic door holders	None	1. Increase staff levels (2 staff per tour group).
2. Install supplemental handrail on up side of helical stair		2. Enhance combustible management in core spaces.
3. Modify stair between 6P and 7P		3. Manage total occupant load in Statue via tour groups.
4. Install handrails on exterior masonry stairs leading from 3P to top of Fort Wood.		4. Train tour staff to begin evacuation immediately upon alarm.

Design Package B

- *Minor Structural Improvements, Administrative Controls, and Fire Protection System Improvements*

Structural Improvements	Fire Protection System Improvements	NPS Administrative Needs
1. Install magnetic door holders	1. Provide voice alarm communication system	1. Increase staff levels (2 staff per tour group).
2. Install supplemental handrail on up side of helical stair	2. Provide code-compliant exit signage , modify to indicate exits at 3P.	2. Enhance combustible management in core spaces.
3. Modify stair between 6P and 7P	3. Provide ceiling level lobby smoke exhaust	3. Manage total occupant load in Statue via tour groups.
4. Install handrails on exterior masonry stairs leading from 3P to top of Fort Wood.	4. Provide high level smoke exhaust from museum space	4. Train tour staff to begin evacuation immediately upon alarm.

Design Package C

- *Major Structural Improvements, Administrative Controls, and Fire Protection System Improvements*

Structural Improvements	Fire Protection System Improvements	NPS Administrative Needs
1. Install magnetic door holders	1. Provide voice alarm communication system	1. Increase staff levels (2 staff per tour group).
2. Install supplemental handrail on up side of helical stair	2. Provide code-compliant exit signage , modify to indicate exits at 3P.	2. Enhance combustible management in core spaces.
3. Modify stair between 6P and 7P	3. Provide ceiling level lobby smoke exhaust	3. Manage total occupant load in Statue via tour groups.
4. Install handrails on exterior masonry stairs leading from 3P to top of Fort Wood.	4. Provide high level smoke exhaust from museum space	4. Train tour staff to begin evacuation immediately upon alarm.
5. Provide 2 remote enclosed code-compliant exit enclosures in Pedestal	5. Provide stair pressurization systems	
6. Provide smoke separation between 6P and 7P.		
7. Separate lobby stairs with minimum 1 hr. rated construction.		

Task 5: Risk Analysis

- A qualitative risk assessment was performed to assess the risk associated with a fire hazard/event.
- A risk ranking approach was used to evaluate risk as a function of:
  - Frequency.
  - Consequence.

Frequency

- *Anticipated* – Fire events that are likely, occur frequently during the life of the Monument.
  - *Small fires (e.g. trash fire)*
- *Possible* – Fire events that are likely, occur some time over the life of the Monument.
  - *Moderate fires / sprinkler suppressed fires*
  - *Failure of passive separation?*
- *Unlikely* – Fire events that are unlikely, but could occur over the life of the Monument.
  - *Larger fires / sprinkler controlled fires (e.g. shielded fire)*
  - *Failure of passive separation?*
- *Improbable* – Fire events that are so unlikely it can be assumed occurrence was not experienced.
  - *Large fires with sprinkler / passive separation failure*

Consequence

- *Severe – RSET > ASET + 60 sec.*
- *High – (ASET – 60 sec.) < RSET < (ASET + 60 sec.)*
- *Moderate – RSET < ASET - 60 sec.*
- *Low – RSET << ASET*

Risk Ranking Matrix

- Figure 8-1 in report:

Consequence					
	Severe	9	5	2	1
	High	13	8	4	3
	Moderate	15	12	7	6
	Low	16	14	11	10
		Improbable	**Unlikely**	**Possible**	**Anticipated**
		Frequency			

Ranking Index	**Suggested Risk Level**
1-2	Extreme Risk
3-5	High Risk
6-9	Moderate Risk
10-16	Low Risk

Task 6: Alternatives Assessment

- Event tree matrices (decision trees) used to evaluate risk.
  - Crown usage and
  - Fire events / failure modes.
- Failure modes considered both equipment and administrative failures:
  - *Sprinklers Fail to Control Fire*
  - *Response Time Delayed*
  - *Combustible Controls*
  - *Open Doors (Indirect)*
  - *Open Doors (Direct)*

Allow Unlimited Crown Access – No Additional Changes

Fire Location	Fire Scenario	No Failures	Sprinklers Fail to Control Fire	Administrative Control Failures				Statue Assumed Response (Pre-Evac) Time	Risk Level / Hazard Index
				Response Time Delayed	Comb. Controls	Open Doors (Ind.)	Open Doors (Direct)		
Adjacent Spaces	Small Fire	X						30 sec. - 6 min.	
						X		30 sec. - 6 min.	
							X	30 sec. - 6 min.	
	Large Fire		X					30 sec. - 6 min.	
			X			X		30 sec. - 6 min.	
			X				X	30 sec. - 6 min.	
Core Spaces	Small Fire (Statue)	X						30 sec. - 6 min.	
	Small Fire (Pedestal)	X						30 sec. - 6 min.	
	Large Fire		X		X		X	30 sec. - 6 min.	
	Flamm. Liquid Fire	X						30 sec. - 6 min.	

Extreme Risk High Risk Moderate Risk Low Risk

Provide Guided Tour Crown Access – With Minor Structural Changes

Fire Location	Fire Scenario	No Failures	Sprinklers Fail to Control Fire	Administrative Control Failures				Statue Assumed Response (Pre-Evac) Time	Risk Level / Hazard Index
				Response Time Delayed	Comb. Controls	Open Doors (Ind.)	Open Doors (Direct)		
Adjacent Spaces	Small Fire	X						0 - 30 sec.	
				X				30 sec. - 3 min.	
						X		0 - 30 sec.	
							X	0 - 30 sec.	
				X		X		30 sec. - 3 min.	
				X			X	30 sec. - 3 min.	
	Large Fire		X					0 - 30 sec.	
			X	X				30 sec. - 3 min.	
			X			X		0 - 30 sec.	
			X				X	0 - 30 sec.	
			X	X		X		30 sec. - 3 min.	
			X	X			X	30 sec. - 3 min.	
Core Spaces	Small Fire (Statue)	X						0 - 30 sec.	
				X				30 sec. - 3 min.	
	Small Fire (Pedestal)	X						0 - 30 sec.	
				X				30 sec. - 3 min.	
	Large Fire		X		X		X	0 - 30 sec.	
			X	X	X		X	30 sec. - 3 min.	
	Flamm. Liquid Fire	X						0 - 30 sec.	

Extreme Risk High Risk Moderate Risk Low Risk

Provide Guided Tour Crown Access – With Major Changes

Fire Location	Fire Scenario	No Failures	Sprinklers Fail to Control Fire	Administrative Control Failures: Response Time Delayed	Administrative Control Failures: Comb. Controls	Administrative Control Failures: Open Doors (Ind.)	Administrative Control Failures: Open Doors (Direct)	Statue Assumed Response (Pre-Evac) Time	Risk Level / Hazard Index: Pedestal	Risk Level / Hazard Index: Statue
Adjacent Spaces	Small Fire	X						0 - 30 sec.		
				X				30 sec. - 3 min.		
						X		0 - 30 sec.		
							X	0 - 30 sec.		
				X		X		30 sec. - 3 min.		
				X			X	30 sec. - 3 min.		
	Large Fire		X					0 - 30 sec.		
			X	X				30 sec. - 3 min.		
			X			X		0 - 30 sec.		
			X				X	0 - 30 sec.		
			X	X		X		30 sec. - 3 min.		
			X	X			X	30 sec. - 3 min.		
Core Spaces	Small Fire (Statue)	X						0 - 30 sec.		
				X				30 sec. - 3 min.		
	Small Fire (Pedestal)	X						0 - 30 sec.		
				X				30 sec. - 3 min.		
	Large Fire		X		X		X	0 - 30 sec.		
			X	X	X		X	30 sec. - 3 min.		
	Flamm. Liquid Fire	X						0 - 30 sec.		

Extreme Risk High Risk Moderate Risk Low Risk

Selected Design Package - C

- *Major Structural Improvements, Administrative Controls, and Fire Protection System Improvements*

Structural Improvements	Fire Protection System Improvements	NPS Administrative Needs
1. Install magnetic door holders	1. Provide voice alarm communication system	1. Increase staff levels (2 staff per tour group).
2. Install supplemental handrail on up side of helical stair	2. Provide code-compliant exit signage , modify to indicate exits at 3P.	2. Enhance combustible management in core spaces.
3. Modify stair between 6P and 7P	3. Provide ceiling level lobby smoke exhaust	3. Manage total occupant load in Statue via tour groups.
4. Install handrails on exterior masonry stairs leading from 3P to top of Fort Wood.	4. Provide high level smoke exhaust from museum space	4. Train tour staff to begin evacuation immediately upon alarm.
5. Provide 2 remote enclosed code-compliant exit enclosures in Pedestal	5. Provide stair pressurization systems	
6. Provide smoke separation between 6P and 7P.		
7. Separate lobby stairs with minimum 1 hr. rated construction.		

Summary

- Is there any way to satisfy code requirements with respect to access to the Crown? What physical changes to the structure would be required to bring the facility into code compliance?
  - Pedestal-compliant
  - Crown- safer
  - Passive fire protection, smoke control, alarm/notification enhancements provided as part of design package.

Summary

- If access to the Crown cannot be made code compliant, how can the NPS minimize the life and safety risks to staff, visitors, and emergency management personnel? How many people could be safely accommodated and under what conditions? What operational procedures would need to be in place to allow access?
  - Improvements to physical features.
  - Procedural issues initiated

Construction Status

- Improvements were made to the helical stair to allow guided tours to the crown.
  - New construction basically separates each floor of Pedestal into two separate stairs and an elevator lobby.
  - Crown was re-opened to public on July 4, 2009.
- The Statue of Liberty was closed for renovations to the pedestal.
  - Re-opened – July 4, 2013

Construction Status

- New construction included fully compliant sprinkler system and standpipe in Pedestal. The Statue is still unsprinklered, with the exception of the two upright heads in the Crown which were reconnected during the new construction.
- New code compliant fire alarm system throughout the Pedestal. Analaser air sampling reconnected and corrected.

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Thank You

- Questions?